High Resolution Measurements of Nonlinear Internal Waves and Mixing on the Washington Continental Shelf

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LONG-TERM GOALS

We are interested in the general problems of internal waves and ocean mixing. Knowledge of these is important for advancing the performance of operational and climate models, as well as for understanding local problems such as pollutant dispersal and biological productivity. Most of the ocean's physical and acoustic environments are severely modified by internal waves. In the specific case of nonlinear internal waves (NLIWs), the currents and displacements of the waves are strong enough to impact surface and under-sea operations and communication. The pilot research described here will begin to improve our knowledge and predictive ability of NLIWs and their impacts on the Washington shelf. Additionally, it will form the foundation for better understanding of NLIW generation and propagation and their associated mixing on continental shelves worldwide.

OBJECTIVES

- Measure the time-evolution of wave structure by tracking as many waves as possible from generation to eventual dissipation.

- Quantify dissipation and mixing associated with the waves and identify the processes leading to wave dissipation using our Modular Microstructure Profiler (MMP).

- Identify wave generation sites and evolution using a combination of SAR satellite imagery, Shallow Water Integrated Mapping System (SWIMS) and shipboard acoustics (Biosonics).

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APPROACH

Observations from a real-time mooring that we maintain on the Washington continental shelf indicate an extremely energetic field of nonlinear internal waves (NLIW) propagating onshore. As a fraction of the water depth, their amplitude is among the largest in the world (Alford et al, 2012). The waves propagate through a strongly time-variable sheared coastal jet current, and appear to be generated as remote internal tides shoal onto the shelf break. In this project we used our Shallow Water Integrated Mapping System (SWIMS) and Modular Microstructure Profiler (MMP) instruments to directly measure their spatial structure and mixing, in order to 1) better understand the propagation and dissipation of strongly nonlinear internal waves in sheared currents and 2) characterize their effects on the acoustic, physical and biological environment of the region.

WORK COMPLETED

In May 2014 we tested MMP from APL's local work boat, the R/V Jack Robertson.

In August 2014 we conducted a highly successful 8-day cruise on R/V Oceanus (Figure 1). We used our towed and dropped profilers, the Shallow Water Integrated Mapping System (SWIMS) and the Modular Microstructure Profiler (MMP), as well as moorings, shipboard radar and an echsounder to track the waves as they shoaled. Chris Jackson assisted in obtaining 9 SAR images concurrent with our August 2014 cruise.

Madeleine Hamann, a Scripps graduate student, went on the cruise and has been analyzing the data under the supervision of Matthew Alford.

RESULTS

Observations (Figure 2) included:

1. Direct turbulence measurements following several waves with MMP
2. Extremely high-resolution wave-tracking exercises using ship's radar, echo sounder, and SWIMS (Figure 3), showing detailed evolution and indirect turbulence measurements of 6 waves as they shoaled
3. Detailed, real-time moored measurements at the Cha Ba mooring
4. Additional moored measurements with a bottom-mounted ADCP at the shelf break and five locations inshore of our measurements
5. 36-hour tidally-resolving transects (Figure 4) showing the generation conditions leading to wave formation
6. Nine synthetic aperture images collected during our cruise with assistance from Chris Jackson and Hans Graber (Example in Figure 1)

The dataset is rich and the cruise concluded less than one month ago. However, based on these data, we have already determined the following preliminary results:

1. We tracked several energetic waves from well east of Cha Ba to the 30-m isobath. An example wave plotted began as a 3-wave packet (Figure 3, left), steepening and spawning a fourth wave (not shown). By the 6th transit (right), the wave has transitioned into waves of elevation.
2. The waves appear to begin propagating toward the NNE (35 degrees True) near the shelf break, and near Cha Ba turn toward 80 degrees True. We hypothesize that this occurs as the waves encounter the sheared southward coastal jet.
3. The waves are extremely turbulent (Figure 3, gray contours), and often show turbulence at the trailing edge and in the core of the waves as observed by Moum et al (2003).

IMPACT/APPLICATIONS

The Washington waves are extremely strong, but completely uncharacterized prior to this work. An assessment of them will allow determination of 1) their possible impact on navigation; 2) their possible effect in mixing and setting local watermass properties; and 3) the effect of their turbulence and transport on the local ecosystem. Additionally, a general understanding of waves in sheared currents will benefit a variety of problems.

RELATED PROJECTS

This project would not have been possible without funds from a related award to transition SWIMS and MMP to Alford's group from Mike Gregg's.

REFERENCES

Alford, M H, John B Mickett, Shuang Zhang, Zhongxiang Zhao, and Jan Newton. Internal waves on the Washington continental shelf. Oceanography, 25(2):66–79, 2012.

Moum, J D, D M Farmer, W D Smyth, L Armi, and S Vagle. Structure and generation of turbulence at interfaces strained by internal solitary waves propagating shoreward over the continental shelf. J. Phys. Oceanogr., 33:2093–2292, 2003.

PUBLICATIONS

None.

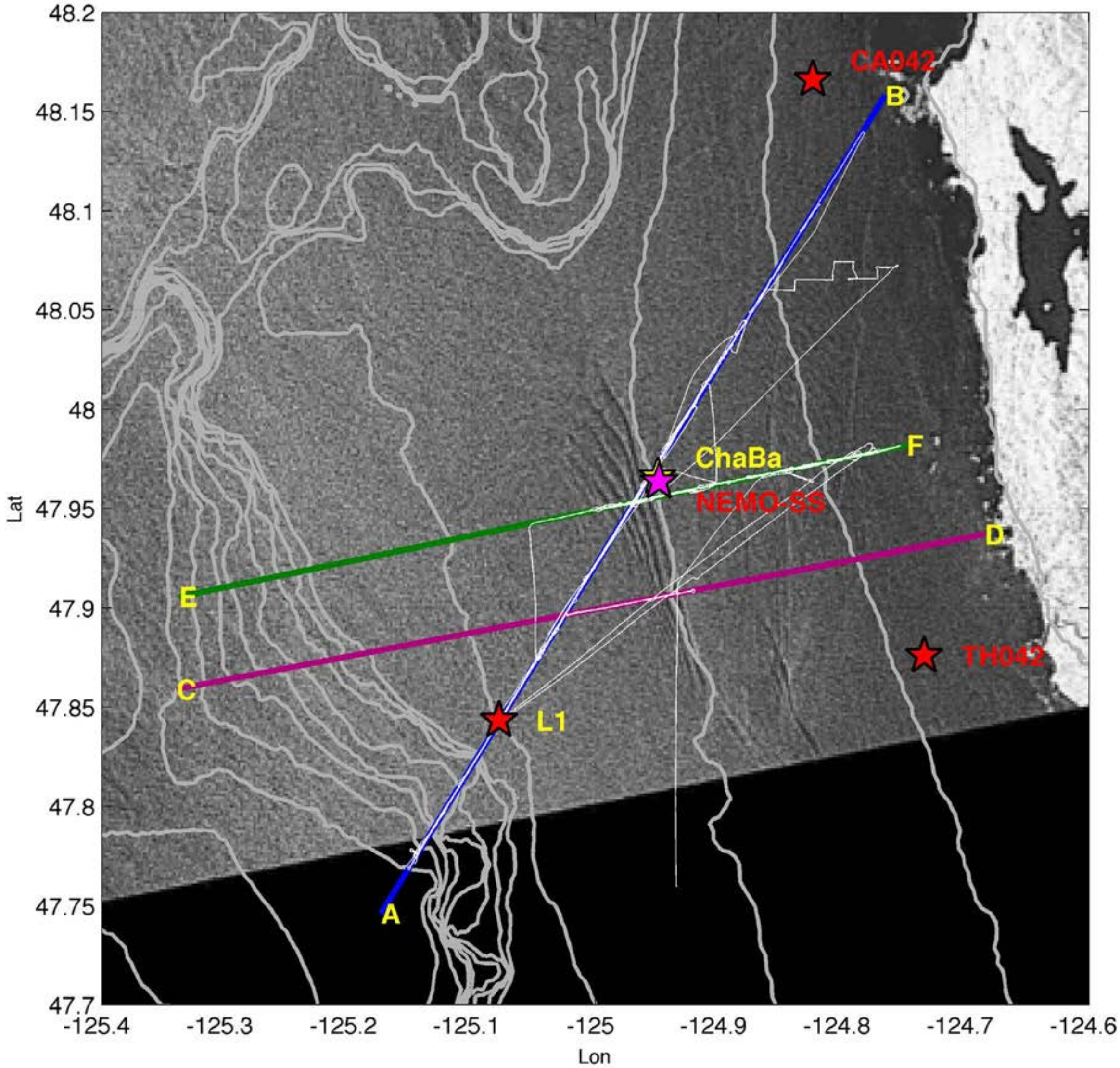

Figure 1: High Resolution bathymetry contours of the study region, mooring locations and survey lines. Synthetic aperture radar (SAR) imagery showing the wave crests traveling onshore is over plotted. Contours are every 50 m until 500 m, and then every 200 m after that.

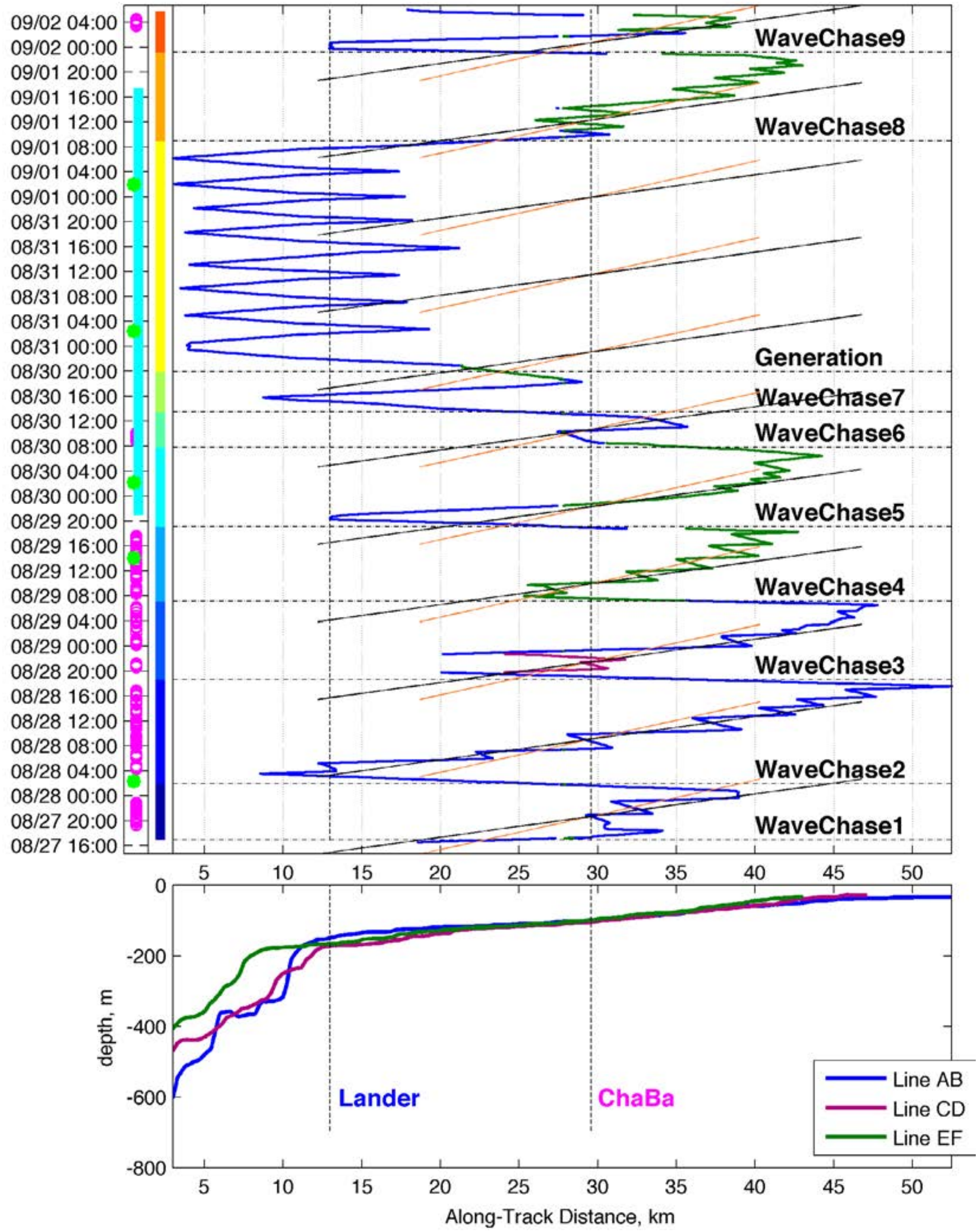

Figure 2: Hovmuller diagram of cruise operations. X axis is cross-shelf distance (bathymetry shown at bottom). Ship track (black) and wave propagation speed at 0.5 m/s (yellow) and 0.8 m/s (black) are shown. Horizontal black lines are times of SAR image collections. Times are plotted at left of SWIMS (cyan) and MMP profiles (pink). Vertical dashed lines are the ADCP lander and Cha Ba locations.

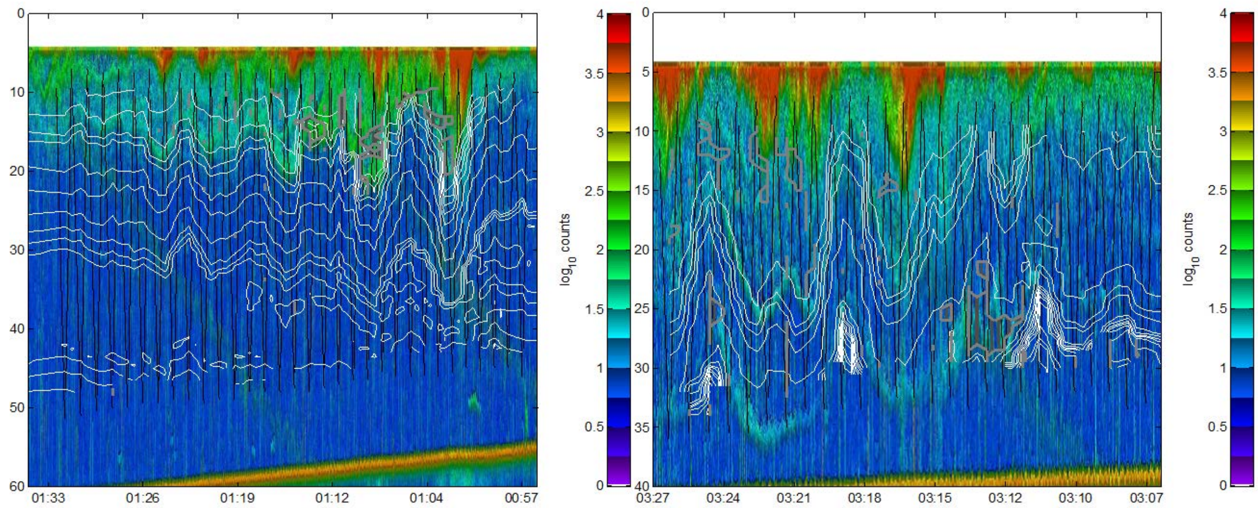

Figure 3: Sample SWIMS/Biosonics sections showing repeated occupations of the same wave as it shoaled. The sawtooth SWIMS track lines are shown (note profiles are not yet offset for lateral distance of SWIMS behind ship). White lines are temperature contours and gray lines surround regions of high dissipation rate computed from overturns. Note these images are plotted versus time and so are distorted by Doppler shifting, which will be corrected for in the detailed analysis.

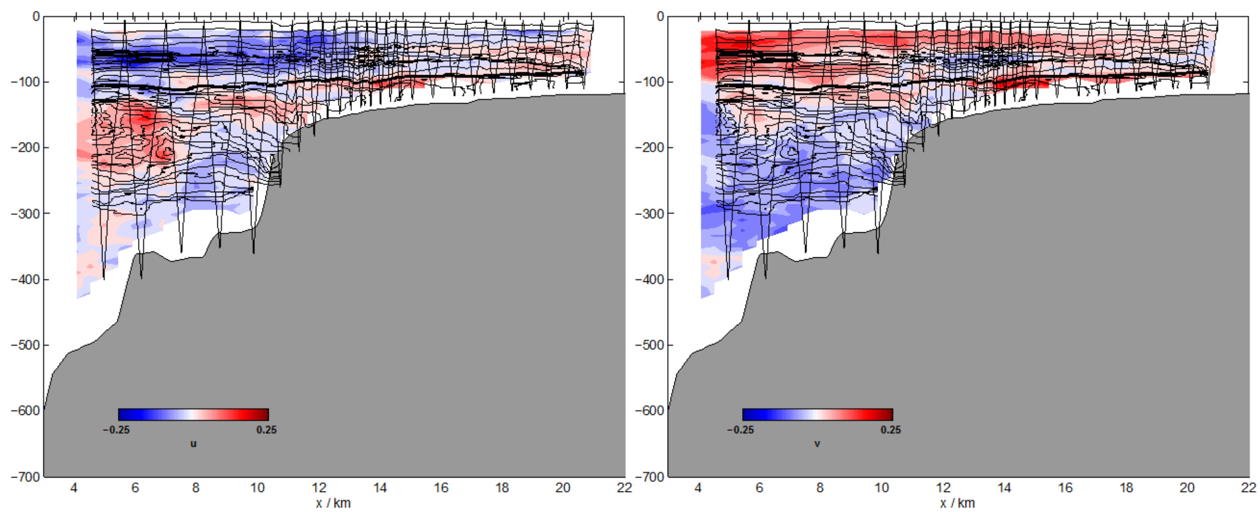

Figure 4: Sample sections showing u (left) and v (right) during our shelf break surveys. The sawtooth SWIMS track lines are shown (note profiles are not yet offset for lateral distance of SWIMS behind ship). Black lines are temperature contours.